COMPARISON OF TWO DIGITAL PHOTOGRAMMETRIC SYSTEMS WITH EMPHASIS ON DTM GENERATION: CASE STUDY GLACIER MEASUREMENT

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Commission IV, Working Group 4

KEY WORDS: Softcopy Photogrammetric Systems, Comparison Softcopy Systems, Glacier DEM/DTM Generation, Matching, Accuracy, 3-D, Test

ABSTRACT

The aim of this project was twofold. Firstly, we wanted to compare two digital photogrammetric systems and especially check their performance regarding DTM generation. The two systems are the Leica/Helava DPW 770 and VirtuoZo, that has been developed by the Wuhan Technical University of Surveying and Mapping, China and Geonautics Pty Ltd, Australia and is being marketed by VirtuoZo Systems Pty Ltd, Australia. The second aim was to test whether DTM generation could be applied in mountainous regions that include glaciers. Due to the irregularity of the terrain and partly the form and image texture of glaciers it was not clear whether such approaches could yield usable results. The project was of particular interest to the glaciologists at ETH that regularly monitor the volume and displacement of glaciers in Switzerland and other parts of the world. After an overview of the two systems, the matching algorithms and the accuracy analysis of the automatically generated DTMs by using ca. 8,700 manually measured points are presented. The accuracy is equal to that of manual measurements, if big blunders are excluded. The paper also addresses and comments on the DTM strategies and editing tools of the systems, makes a short comparison between analytical and digital systems, and reports on different system aspects like ease of use, flexibility, ability to import and use external a priori information, ability to access intermediate results, time aspects etc.

1. INTRODUCTION

The Leica/Helava DPW 770 is an advanced system with very extensive functions and a price of over 300,000 SFr. The software runs on a 50 MHz Sun Sparc 10 (in our case) and uses a second monitor for stereoscopic display of images with passive polarised glasses. The VirtuoZo is purely software based and runs on Silicon Graphics (in our case an IRIS Indigo Elan Graphics) with stereo capabilities using CrystalEyes active shutter glasses. Its functionality is not as extensive as the one of the DPW 770 but its price is correspondingly lower (ca. 50,000 SFr.). More details on the systems can be found in Miller et al., 1992, and Zhang et al., 1994.

The data source for the study consisted of three photographs along a strip with 85% overlap at 1:10,000 scale. The images were taken in September and included the glacier tongue (the most important glacier part for the glaciologists). The height range in the scene was ca. 700 m. The negatives were scanned on a Zeiss/Intergraph PS 1 with 15 microns and were later subsampled to 30 microns pixel size. The 15 micron images were too large to be processed by VirtuoZo, so the automatic DTM generation and the accuracy comparison was based on the 30 micron images. The control points were measured geodetically with an accuracy of under 1 dm (3-5 points per stereopair). Due to the terrain difficulty and the movement of the glacier only a few permanent control points could be established for glacier monitoring. The image quality of the control points was poor due to their small size, making their identification difficult. A Wild AC1 analytical plotter was used for the measurement of the control and tie points, and the sensor orientation was computed by a bundle adjustment using all three images. This orientation was used in both digital systems, so that the DTM comparison would be more objective. A reference DTM including breaklines covering the glacier and the surrounding mountain slopes was measured on the analytical plotter in order to assess the DTM accuracy of the digital systems (ca. 8700 points). Initial tests for automatic DTM extraction showed that results were poor in regions that had little texture or shadows. This was partly due to the dynamic range of the linear CCD of the scanner which was not high enough to accommodate the high contrast of the scene and the way the photographs were taken (exposure was optimised for glacier, hence the surrounding terrain appeared very dark). Thus, a strong contrast enhancement was performed with a Wallis filter (see Figure 1) which lead to a significant improvement in feature recognition and image matching.

2. DTM GENERATION

Using the digital photogrammetric systems, DTMs, orthoimages and 3D perspective views (see Figure 2) were generated from one model. In both systems the algorithms for automatic DTM generation use epipolar images, and image pyramids for derivation of approximations for the position of conjugate points. Both systems use crosscorrelation for image matching, whereby VirtuoZo also uses another global relaxation matching technique at the end phase in order to check whether the matching results of each point are consistent with the results in its neighbourhood and thus detect blunders. DPW 770 matches at a regular grid in object space, VirtuoZo uses a regular grid in image space (thus, a subsequent DTM grid interpolation is necessary). Both systems permit the selection of one out of many matching strategies. In both cases a strategy for "steep terrain" was selected (for DPW

Fig. 1. An image region from the second pyramid level. Pixels in white have grey value zero. Left: the original image ; Right: after Wallis filtering.

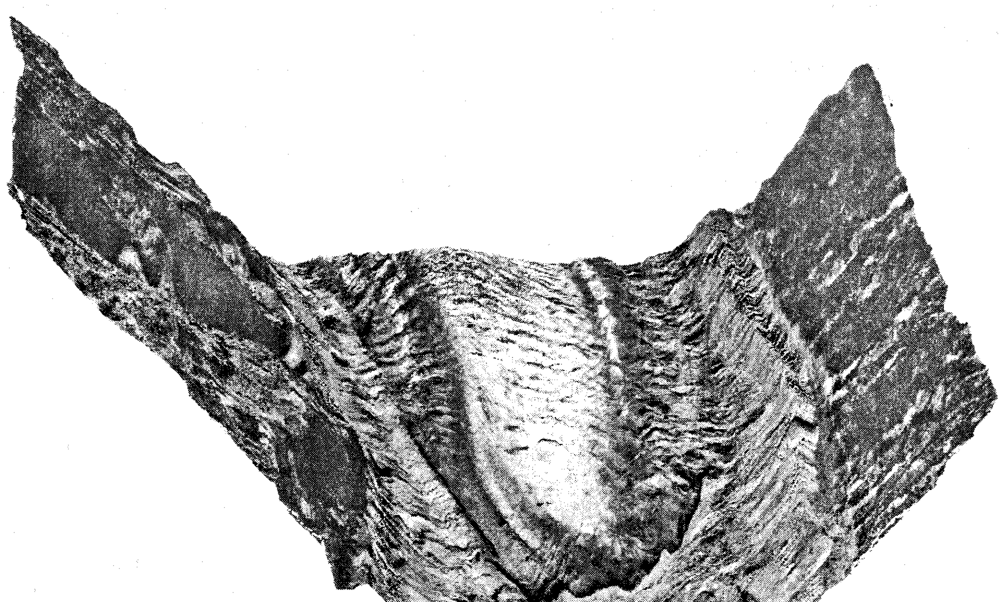

Fig. 2. 3D parallel view of the Morteratsch glacier (exaggeration factor 1.5).

the steep_1 strategy). In VirtuoZo the patch size that was used for crosscorrelation was 9 x 9 pixels and the distance between match points was 9 pixels, i.e. ca. 2.7 m in object space, resulting in 467,000 match points. In DPW 770 the patch size is selected automatically based on the strategy and the pyramid level (in our case 15 x 15 pixels). The selected DTM grid spacing was 2.5 m resulting in ca. 462,000 DTM points. VirtuoZo used four pyramid levels (incl. the original image) and the DPW 770 eight processing passes that included six pyramid levels (for some pyramid levels there are double processing passes).

3. EVALUATION OF DTM ACCURACY

First, a regular DTM grid with a 2.5 m spacing was interpolated from the VirtuoZo matching results using an own programme. VirtuoZo is unable to interpolate a DTM grid in the usual N-S/E-W direction, although according to the documentation it should be able to do so. Then, the manually measured points were interpolated in the DTM grids in order to evaluate the accuracy of the latter (see Tables 1 and 2; for the version of DPW in the whole image and points with quality code > 32, i.e. reliable points, see section 4.2). These results were influenced by several blunders of up to ca. 100 m in different difficult regions (usually regions of little or no texture, and abrupt terrain discontinuities, see small rectangles in Figure 3). Thus, a second accuracy analysis was performed in a region where no big blunders in the matching results occurred (see big rectangle in Figure 3). The number of manually measured points in the region was ca. 4,000. The DTM accuracy in this region was much higher (see Table 1) and is an indication of what accuracy can be achieved by automatic DTM generation algorithms, if the results have no big blunders. The errors in the second smaller region are shown as grey level image in Figure 4. In all cases no editing of the image matching results was performed. In a practical situation all very dark regions could be excluded a priori and thus many blunders could be avoided and processing time could be reduced. The accuracy of both systems is very similar, as Tables 1 and 2 indicate. Compared to VirtuoZo, DPW 770 has slightly better RMS and maximum error in the whole image, but its error distribution is slightly worse. In the region without big blunders the accuracy of both systems is very similar and quite high (ca. 99% of the points have an error of less than 3 m = 3 RMS). Contours from the VirtuoZo results are a bit more noisy than the ones from DPW, but this is probably due to the smaller patch size. The small average in all cases shows that no large systematic errors occurred. The main problem is the existence of blunders. There are not many, but they are big. The DTM accuracy that was requested by the glaciologists (0.5 m) was not achieved. However, for the low base/height ratio of the stereo model and the poor control point configuration, the pointing accuracy in height that could be achieved with good manual measurements was one meter. This accuracy was achieved by both systems but only after exclusion of the big blunders. Thus, it can be stated that glaciers (or other type of terrain with similar difficulties) can be measured by automated DTM procedures, but efficient, fast and comfortable methods for the automatic detection and exclusion of blunders are still missing.

The performance of these digital systems was checked in a second test, which will be presented in another paper. However, we think it is useful to briefly present these results here for comparison. The second test involved a stereo pair with image scale 1:68,000 and an overlap of ca. 50%. The terrain was rolling (height differences of ca. 400 m) but quite tricky and difficult including many forested and small urban areas. The digital images had a pixel size of 25 microns. The orientation of the images had an accuracy of ca. 1 m and was used in both digital systems. The reference DTM was the DHM25 of the Swiss Federal Office of Topography with an accuracy (RMS) of 1.8 m. With the DPW 770 the new IOR (Iterative Orthophoto Refinement) strategy was used. The green layer of the scanned 1:25,000 topographic map was used to separate between forested and nonforested areas. Thus, three accuracy tests were performed (in forested, nonforested and whole area). The accuracy in forested areas can not be checked because the reference DTM does not include the height of the trees. In the nonforested areas the RMS error for both systems (ca. 130,000 points) was 2.6 m, a result that is very good, if the small image scale is considered, and very close to the accuracy of the reference DTM. In both systems 99% of the points had an error of less than 8 m (3 RMS), and the error distribution was very similar.

4. COMMENTS ON AUTOMATED DSM GENERATION

4.1. DTM Strategies

Both systems permit the selection of a matching strategy. VirtuoZo just offers the possibility to choose one of five strategies, mainly depending on the terrain slope and form, without permitting the setting of any other parameters except the patch size used in matching and the grid spacing of the image grid where matching is performed. We used the strategies 5 (rugged terrain) and 3 (smooth hillocks) and the results were completely identical! DPW offers three basic strategies (flat, rolling and steep terrain) and four other strategies for tie point measurement and mosaicking. When the terrain has mixed form and slopes, the steep strategy should be preferred. Each of the basic strategies comes in four versions depending on accuracy versus speed, elimination of trees and buildings, and DTM thin-out in flat areas when the DTM is dense. In the new software release there are also seven additional strategies (still in experimental stage) employing the IOR matching method. The user can modify any strategy file or create its own file. Each strategy file consists of several processing passes, each pass working on images of a certain pyramid level. The number of passes/pyramid levels is 6/4, 8/5, 8/6 for the flat, rolling and steep strategies respectively. Each pass has 38 or 44 parameters for the old and new strategy file versions respectively. The strategy files are hard to read and their documentation poor. Some of the parameters are not used but the user does not know which. Others have wrong values, but again it is unknown whether they are used. There are some parameters that are used and are not optimally set, e.g. the patch size is 15 x 15 pixels for all strategies and processing passes; larger slopes and less smoothing is permitted in the upper pyramid levels etc. The parameters for spike deletion do not seem to work well, while those for deletion of obstructions (houses and trees) are too coarse, do not take into account the obstruction height and can lead to removal of tips of hills etc. Other parameters are fixed, although they should be adaptively derived from the data itself. For example in the steep strategies the pyramid levels are 6. This value may not be sufficient for large parallaxes. The optimal value could be given by the user or estimated from the data by a coarse matching. Concluding, the strategy files and the algorithms behind them, although they need definite improvement, are generally positive. However, a user with little knowledge will use these strategies as a black box and might run into problems without being able to understand why. The sophisticated user needs more information on the effect of the parameters, the internal computations and the use of the thresholds. In this respect the supplied documentation is insufficient.

A new Automatic Terrain Extraction (ATE), provisionally called Adaptive ATE (AATE), is under development for DPW. Using a rule file and an inference engine it will adaptively tune matching parameters depending on the terrain and image content, and

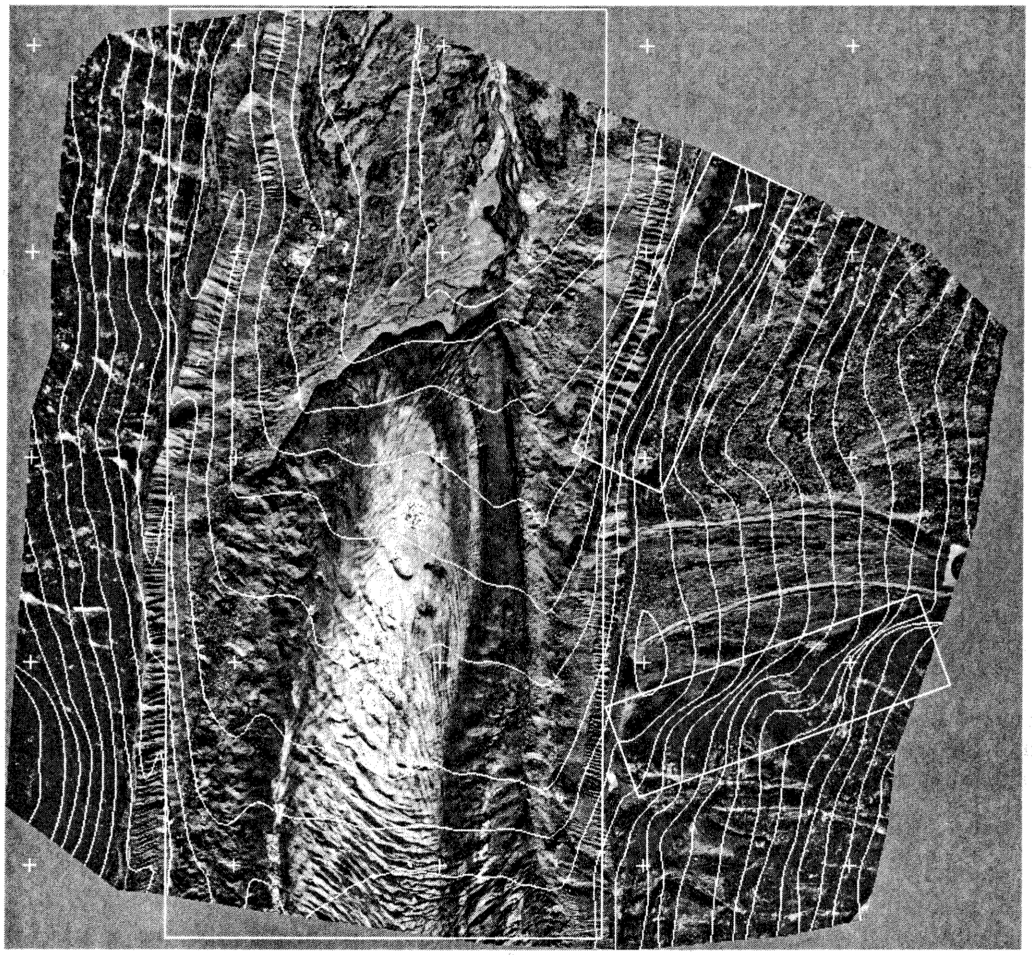

Fig. 3. Orthoimage with overlaid contours (with 30 m interval) and tick marks every 400 m. Data are derived from the DPW 770 results. Small rectangles show regions of big blunders, and the big rectangle shows the region without big blunders where a separate accuracy analysis was performed.

Table 1. Statistics of height differences between manual and automatic measurements.

Version	Number of points compared	Time[1] required (sec) / number of match points	Maximum absolute (m)	Average (m)	RMS (m)
DPW 770 (whole image) all points / points with code[2] > 32	8728/ 356,000	5340 / 462,000	87.0/ 70.7	0.28/ 0.28	3.53/ 1.38
DPW 770 (region without big blunders)	3997		16.5	0.15	1.08
VirtuoZo (whole image)	8594	860 / 467,000	103.5	0.27	4.13
VirtuoZo (region without big blunders)	3997		14.6	0.21	0.96

1 The time refers to matching only (for VirtuoZo it also includes the generation of the image pyramid). For DPW 770 the elapsed time is given, for VirtuoZo the CPU time. For VirtuoZo the times for epipolar resampling and DTM grid interpolation were 340 sec and 110 sec respectively. Latter included 480,000 output points and was used only for timing purposes.

2 Quality code provided by DPW. Points with code > 32 are considered reliable.

Table 2. Percentage of points for various classes of absolute differences between manual and automatic measurements (in m).

Version	0 - 2	2 - 3	3 - 4	4 - 6	6 - 9	9 - 15	> 15
DPW 770 (whole image) all points / points with code > 32	85.65/ 90.12	5.35/ 5.57	2.80/ 2.20	2.69/ 1.55	1.90/ 0.47	0.94/ 0.09	0.68/ 0.00
DPW 770 (region without big blunders)	96.75	1.73	0.63	0.40	0.28	0.18	0.05
VirtuoZo (whole image)	89.17	3.99	2.26	1.87	1.05	0.81	0.85
VirtuoZo (region without big blunders)	97.70	1.38	0.35	0.25	0.18	0.15	

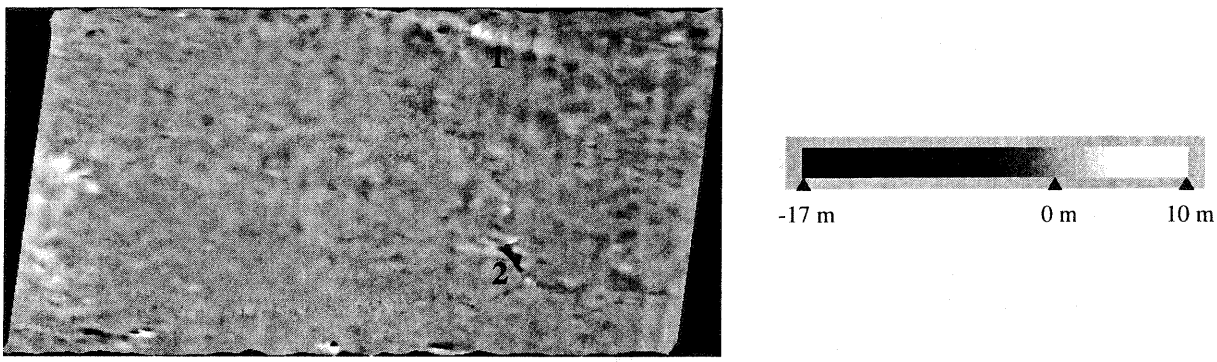

Fig. 4. Accuracy analysis in the region without big blunders. The differences between manual results and DPW 770 (VirtuoZo results were very similar) are displayed as grey values. The range -4 to 4 m has been strongly stretched for better visualisation. 1 ...big errors due to steep slopes, 2 ...errors at the tip of the glacier tongue.

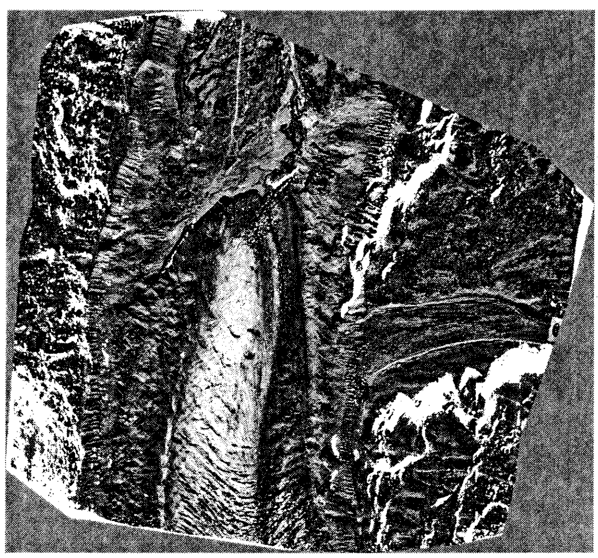

Fig. 5. Low quality code of DPW matching results: Points with quality code < 33, i.e. unreliable points, are displayed in white and overlayed on an orthoimage. They mostly lie in areas with shadows or no texture (compare to Figure 3).

processing phase. It will also compensate for y-parallax, perform epipolar resampling on the fly, and use more than two images.

4.2. DTM Editing

Efficient, fast and comfortable methods for the automatic detection and exclusion of blunders are still missing. As an example big errors (so called spikes) could be easily detected and corrected by a median filtering but such functions are not provided or not correctly implemented by these two systems. Since some blunders may always remain in the data set, a manual editing will still be necessary. The tools provided by digital photogrammetric systems must be such that all blunders are included in a set of suspicious points that is presented to the user, permitting him an easy manual or semiautomatic remeasurement. Otherwise, the user must visually control hundred thousands of points. Both systems provide certain indications of the matching quality and means to edit the data. DPW 770 stores in a file a quality code from 0 to 100. Points with code less than 33 are considered unreliable and are mostly interpolated from other good points (see Figure 5). In a test all these points (11.2%) were deleted and the rest was interpolated in a 5 m regular grid of the manual measurements for accuracy analysis (see Tables 1 and 2). Only 39% of the deleted points (i.e. ca. 4% of all points) were in reality blunders (error > 3 m). The resulting RMS was much lower and the big blunders were severely reduced. Thus, operationally all low quality code points could be deleted and manual measurements could be made to fill-in the resulting DTM gaps. Still, the remaining blunders (> 3 m) are 4% (ca. 15,000 points) and not indicated by the quality code. VirtuoZo divides the points in three quality classes that are displayed on the screen with different colours. The worst class includes points that have been interpolated. Again blunders are included in the "reliable" classes and additionally this quality code is not saved in any file for user access. So, the quality measures provided by the systems must be made more reliable and additional diagnostic tools should be used. However, DPW led after deletion of the low quality code points to 2.5% less blunders than VirtuoZo, which means less editing time or higher DTM accuracy, if no manual editing is performed.

Both systems provide tools to indicate errors (contours, 3D views, overlay of contours on orthoimages or in the stereomodel) and means to edit the data pointwise or regionwise, but since the blunders are not reliably highlighted, the user must control the whole data set. The editing tools should, at least partially, used before matching (e.g. exclusion of textureless areas, water bodies etc.). Thus, time is saved and the given information can be used in matching. Nevertheless, automatic DTM generation does have certain advantages over manual measurements like processing speed (over 100 points per sec) and the possibility to derive a very dense DTM. This is significant because it leads to a much more accurate terrain representation (implicit measurement of breaklines, form lines etc.).

5. COMPARISON BETWEEN DIGITAL AND ANALYTICAL SYSTEMS - CONCLUSIONS

Compared to analytical plotters digital photogrammetric systems show following characteristics. The price of digital photogrammetric systems is similar to much lower that the one of the analytical plotters. They also offer additional functionality like geometric sensor models for satellite imagery, image rectification, orthoimage and orthoimage map generation, mosaicking, 3D perspective views, animation and flyovers, image processing, support of many input/output raster and vector data formats etc. The cheaper systems however do not have all these functions. VirtuoZo does not have for example triangulation, mapping software (except simple feature digitisation with an attribute code using an extra package), orthoimage map generation (except of overlay of contours on orthoimages), animation and flyovers, and image rectification. Deficiencies that were observed during this project include the following:

- The systems are not open and flexible enough. The content and format of some files is unknown (e.g. metadata image files with orientation etc. in DPW). Intermediate results like pixel and photo coordinates can not be accessed. The user is bound to the standard streamlined processing flow, so limited operations (like import of a foreign orthoimage and creation of an orthoimage map in DPW) are not possible or very cumbersome.
- VirtuoZo does not provide some common input/output formats. Both systems input uncommon image formats (raw, VITEC) which leads to an increase of required disk space and processing delays.
- The documentation, especially of VirtuoZo, is poor and explains very little on what exactly and how it is done.

Fully fledged systems like the DPW 770 are quite complicated to handle and require significant training, whereby VirtuoZo is easy-to-use and its user interface quite intuitive. The size of digital data is still a problem. Large images can only be processed a few at a time or not at all. Many processes appear as a blackbox to the user, case which is not always desirable especially in education and research. Digital photogrammetric systems have to a large extent transferred the working mode of the analytical plotters in the digital domain. Thus, for example they concentrate on processing of stereo images without exploiting the existing possibility of simultaneous processing of multiple images in order to improve accuracy and reliability of the results (especially for DTM generation and automated feature extraction). Functionality should be extended (semi-automated feature extraction, monoplotting, structuring of measurements, import and integration of other data, data/metadata storage and management, GIS functionality for data analysis). A comparison between DPW 770 and VirtuoZo shows that both systems have their strong and weak points. DPW 770 has more functions, but is also more expensive and complicated to use. VirtuoZo on the other hand offers the advantage of user-friendliness and low price. It can certainly be used for DTM and orthoimage generation, but it is not suitable for aerial triangulation or mapping. Even with their present weaknesses digital photogrammetric systems offer significant advantages in comparison to analytical plotters and can be fully employed in research and professional practise. The expected improvement of their performance, especially in the algorithms and the user interface, will expand their use even further.

Acknowledgements

The authors would like to thank A. Kääb and H. Bösch, Glaciology, ETHZ for proposing the glacier project, supplying data and helping in the recognition of the control points, as well as the students A. Bleisch and C. Räuftlin for their engaged work on this project within their "Praktikum" in photogrammetry.

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